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Surface Treatment Technologies for Boiling Heat Transfer augmentation

ORMAN Łukasz J.[1, a *], RADEK Norbert[1,b] and KAPJOR Andrej[2,c]

[1]Kielce University of Technology, al. Tysiaclecia P.P. 7, 25-314 Kielce, Poland

[2]University of Zilina, Univerzitna 1, 01026 Zilina, Slovakia

[a]orman@tu.kielce.pl, [b]norrad@tu.kielce.pl, [c]andrej.kapjor@fstroj.utc.sk

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Abstract. The paper discusses different methods of surface treatment for the production of efficient phase – change heat exchangers. Special focus is given to sintered metal mesh microstructures and laser treatment. The augmentation of boiling heat transfer is described for meshed surfaces due to their best performance characteristics.

Introduction

There are many techniques of augmenting boiling heat transfer. They can be classified as active and passive methods, depending on whether direct input of external power is necessary. Surface treatment with various methods is a passive technique and generally involves modification of the surface either with mechanical or thermal technologies or application of various types on surface coatings (microstructures). Poniewski [1] gave an overview of microstructures used for boiling heat transfer augmentation. According to the author, heat flux enhancement is caused by such a change in the heater structure that increases a number of active nucleation sites and ensures their stabilised action. Industrial microstructures, sintered or thermally sprayed powder structures as well as metal fibrous, wire mesh and combines structures are, among others, boiling heat transfer enhancing structures. Industrially produced surfaces could be made of sintered metal particles, differently shaped microfins, microstructures with internal tunnels and others. Sintered layers are produced with metal particles of a given diameter and enable obtaining designed porosity and height. Thermal spraying includes plasma, electric arc and flame spraying. In the case of plasma and flame spraying, the coating material is supplied to the burner and sprayed onto the base surface, while the structural material to form porous layers using the electric arc technique comes from the electrodes themselves. Metal fibrous structures are sintered using fine metal fibers. Mesh structures are made of layers of mesh and joined together mechanically or thermally [1]. It is worth noting that even producing roughness on the heat exchanger surface with emery paper can augment boiling heat transfer. This phenomenon is linked with increasing the number of active nucleation sites (locations where vapour bubbles are created and grown) due to increased surface roughness, because such nucleation sites are typically located at cracks or irregularities on the heater surface. The same principle can be behind surface treatment with the laser beam.

The present paper deals with mesh structures, which are often used for heat pipe production and easily available, commercial meshes made of different metals as well as laser treatment of the heater surface.

Sintered metal meshes

The use of metal meshes for boiling heat transfer augmentation is well documented. However, much literature data is given for meshes which were mechanically attached to the heater surface. For example, Rannenberg and Beer [2] presented the results of boiling heat transfer of R-11 and R-113 at atmospheric pressure on a horizontal copper surface covered with 2-9 layers of stainless steel and

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bronze meshes. In this case, the meshes were mechanically attached to the heater surface and improved heat transfer in comparison to the surface without the meshes.

Mechanical attachment may cause high thermal resistance to heat transfer. Consequently, sintering is another technique. It offers the possibility of producing strong bonds due to local melting of the mesh into the base surface of the heater. Li et al. [3] considered water boiling on a horizontal copper heater covered with mesh layers. The structure was sintered at 1030°C in the gas mixture of 75% N_2 and 25% H_2. It was reported that sintering minimised the contact resistance between the meshes and the heater. It was proven that a proper contact results in better heat transfer conditions. Five kinds of meshes were tested, while the number of layers ranged from 2 to 9. All the meshed surfaces augmented boiling in comparison with the smooth surface.

The experiments of the authors were carried out on samples that were prepared in such a way that the meshes were sintered to the copper discs of 3 cm in diameter in the reduction atmosphere of hydrogen and nitrogen to prevent oxidation. The sintering process took place at a temperature that is slightly lower than the melting temperature in order to produce strong bonds between the heater disc and the mesh layers, while preventing melting of the sample altogether. In the analysed case of the copper sample, the sintering temperature amounted to about 920°C. Fig. 1 presents the SEM image of a multi-mesh microstructure. The wires in contact with the heater surface are nearly molten into the base surface (bottom part of Fig. 1a). The wires comprising the microstructure are also typically in very good contact with one another. This minimises thermal resistance and increases conduction through the structure of the layer. However, careful analysis of the figures below indicates that some of the wires comprising the layer are not in proper contact, which leads to increased thermal resistance and lower heat fluxes transferred from such a surface to the boiling liquid. This can be eliminated with a careful production of the samples, which are pressed in a special mechanical clamp, in which they are kept during sintering in the oven.

a) b)

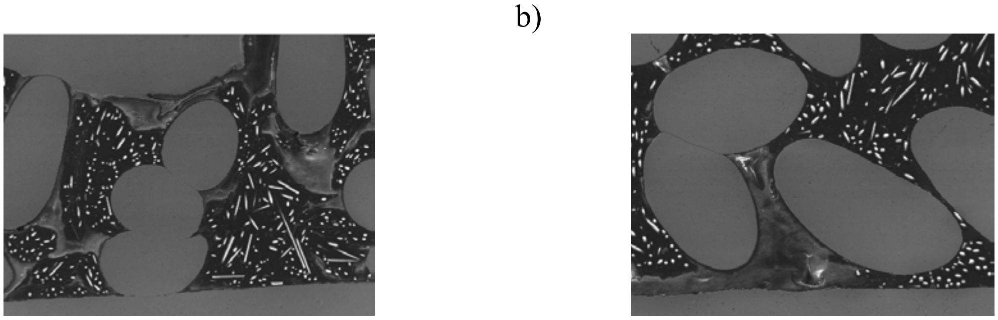

Fig. 1. SEM image of the multilayer copper mesh surface: a) magnification 75x, b) magnification 100x

The application of the multilayer copper meshes augmented boiling heat transfer in comparison to the smooth reference surface. Heat flux (q) can be even several times higher for such treated surfaces than for the surface without any coating at the same temperature difference (θ). Fig. 2 presents the enhancement ratio expressed as the ration of the value of heat flux dissipated from the meshed surface to the heat flux from the smooth surface without such coating. The data has been adopted from the paper by the co-author [4]. Here, distilled water boiling under ambient pressure is considered on the copper heater surface covered with sintered layers of copper meshes. Three different values of the temperature difference have been taken into account for the analyses.

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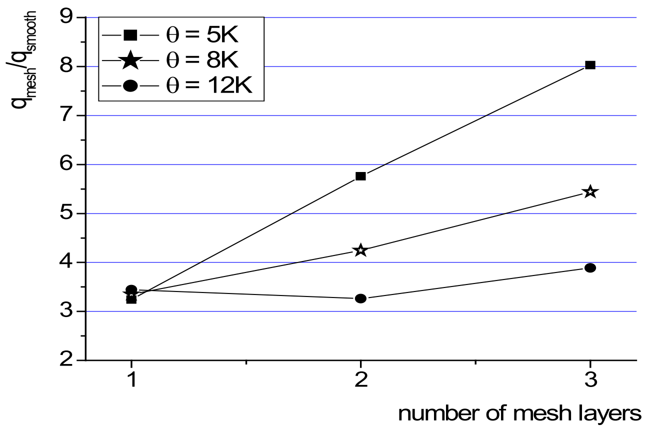

Fig. 2. Enhancement ratio for distilled water boiling

As can be seen in the figure above, the heat flux dissipated from the meshed surface (made of three sintered meshes) can be over eight times higher than for the smooth reference surface without any coating. It is worth noting that heat flux is typically larger as the number of mesh layers is increased and as the temperature difference is lower.

Laser treatment for boiling augmentation

The modification of the surface with the use of the laser beam is another method of surface treatment experimentally analysed by the authors.. This has been discussed by the co-author in [5, 6]. The treatment of the heater surface was conducted with a Nd:YAG type laser working in the pulse mode. The laser spot diameter was 0.7 mm, the beam shift rate: 1200 mm/min, the nozzle-sample distance: 6 mm, while the pulse duration equalled 0.45 ms. Fig. 3 presents the surface morphology of the laser treated heater.

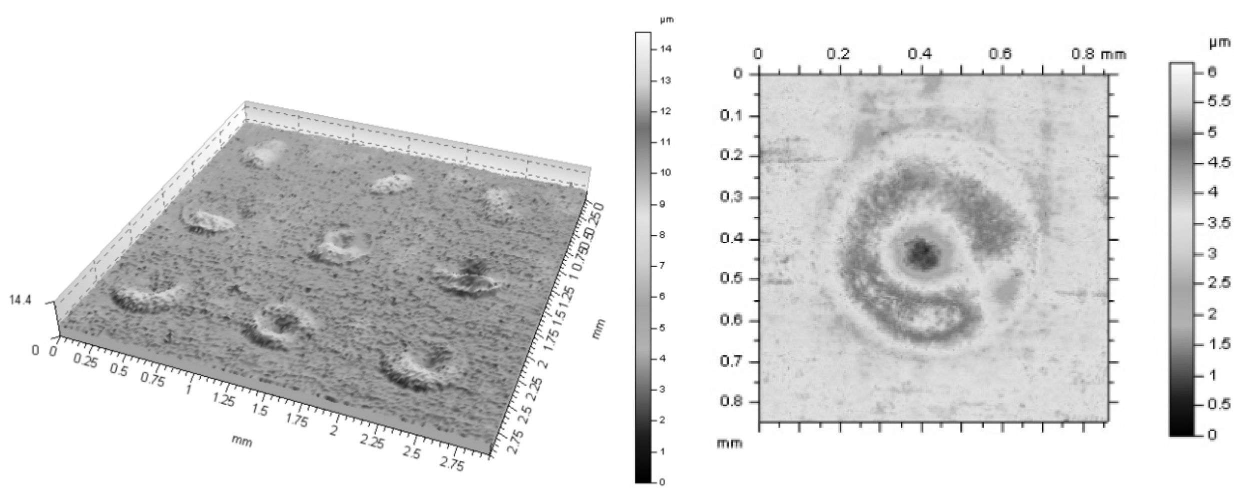

Fig. 3. Surface morphology of the laser treated sample (cavity depth: 2.6 μm, cavity diameter: 0.17 mm)

The application of the laser treatment can lead to increased heat fluxes being dissipated from the heaters. According to the authors' tests a laser treated surface dissipated even twice as much heat flux as the non-treated surface.

Summary
The use of special surface treatment techniques can result in higher heat fluxes that can be dissipated from heaters during boiling heat transfer. Thus, heat exchangers can be smaller and still transfer the same heat fluxes or can dissipate more heat if the surface area remains the same. It offers significant possibilities in many areas of engineering such as for the production of refrigeration devices or electronic cooling units, where phase – change processes of different agents are used. Although the present paper deals with pool boiling, treated surfaces can also be highly effective in the flow boiling heat transfer mode as indicated in [7] and other systems [8].

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